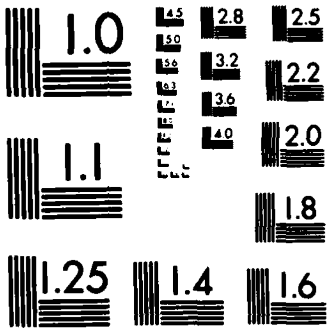
AD-A157 408 ANALYTIC MODELS FOR RADIATION INDUCED LOSS IN OPTICAL FIBERS III TRANSIENT RADIATION EFFECTS(U) ROME AIR DEVELOPMENT CENTER GRIFFISS AFB NY J A WALL FEB 85 1/1

UNCLASSIFIED RADC-TR-85-39 F/G 20/6 NL

END

FILMED

DTIC



MICROCOPY RESOLUTION TEST CHART

DARDS-1963-A

PHOTOGRAPH THIS SHEET

II

LEVEL

1

INVENTORY

AD-A157 408

DTIC ACCESSION NUMBER

RADC-TR-85-39

DOCUMENT IDENTIFICATION

Feb 1985

DISTRIBUTION STATEMENT

ACCESSION FOR		
NTIS	GRA&I	☒
DTIC	TAB	☐
UNANNOUNCED		☐
JUSTIFICATION		
BY		
DISTRIBUTION /		
AVAILABILITY CODES		
DIST	AVAIL AND/OR SPECIAL	
A-1		

DISTRIBUTION STAMP

DTIC

DATE ACCESSIONED

DATE RETURNED

85 7 31 017

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NO.

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-DDAC

DTIC FORM 70A DEC 83 DOCUMENT PROCESSING SHEET PREVIOUS EDITION MAY BE USED UNTIL STOCK IS EXHAUSTED.

1 JXR2 85-27

RADC-TR-85-39
In-House Report
February 1985

AD-A157 408

ANALYTIC MODELS FOR RADIATION INDUCED LOSS IN OPTICAL FIBERS III. TRANSIENT RADIATION EFFECTS - U

James A. Wall

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

NONE

ROME AIR DEVELOPMENT CENTER
Air Force Systems Command
Griffiss Air Force Base, NY 13441-5700

C

FR.

This report has been reviewed by the RADC Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be releasable to the general public, including foreign nations.

RADC-TR-85-39 has been reviewed and is approved for publication.

APPROVED: Bobby L Buchanan

BOBBY L. BUCHANAN, Chief
Rad Hard Elec Tech Branch
Solid State Sciences Division

APPROVED: Harold Roth

HAROLD ROTH, Director
Solid State Sciences Division

FOR THE COMMANDER: John A. Ritz

JOHN A. RITZ
Acting Chief, Plans Office

If your address has changed or if you wish to be removed from the RADC mailing list, or if the addressee is no longer employed by your organization, please notify RADC (ESR) Hanscom AFB MA 01731. This will assist us in maintaining a current mailing list.

Do not return copies of this report unless contractual obligations or notices on a specific document requires that it be returned.

AD A 157 408

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION Unclassified	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution unlimited.
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S) RADC TR-85-39	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION Rome Air Development Center 6b. OFFICE SYMBOL (If applicable) RADC/ESR	7a. NAME OF MONITORING ORGANIZATION Rome Air Development Center (ESR)
6c. ADDRESS (City, State and ZIP Code) Hanscom AFB Massachusetts 01731	7b. ADDRESS (City, State and ZIP Code) Hanscom AFB, MA 01731
8a. NAME OF FUNDING/SPONSORING ORGANIZATION Rome Air Development Ctr. 8b. OFFICE SYMBOL (If applicable) RADC/ESR	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c. ADDRESS (City, State and ZIP Code) Hanscom AFB, MA 01731	10. SOURCE OF FUNDING NOS. PROGRAM ELEMENT NO. 61102F PROJECT NO. 2306 TASK NO. J3 WORK UNIT NO 01

11. TITLE (Include Security Classification) Analytic Models for Radiation Induced Loss in Optical Fibers III. Transient Radiation Effects

12. PERSONAL AUTHOR(S) Wall, James A.

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Yr., Mo., Day)	15. PAGE COUNT
In-House	FROM ______ TO ______	1985 February 21	11

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Optical fibers Radiation effects Analytical models
20	12		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

A number of physical models used to describe the recovery of transient radiation induced loss in optical fibers were evaluated and found unacceptable for various reasons. Based on an approximation to some of these models, the analytic expression

$$L = \frac{a}{1 + bt^n},$$

where L = loss, t = time after pulse, and a, b, and n are constants, was formulated and found to give very good fits to transient radiation effects data obtained at RADC.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS ☐	21. ABSTRACT SECURITY CLASSIFICATION UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL James A. Wall	22b. TELEPHONE NUMBER (Include Area Code) (617) 861-4031 22c. OFFICE SYMBOL ESR

DD FORM 1473, 83 APR — EDITION OF 1 JAN 73 IS OBSOLETE. — UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

Contents

1. INTRODUCTION 1

2. MODEL SELECTION 2

3. DATA FITTING PROCEDURE 4

4. RESULTS 4

5. DISCUSSION 5

REFERENCES 7

Illustrations

1. Fit of Eq. (1) to Data for the Recovery of Transient Radiation Induced Loss in a Germanium-Borosilicate Core Optical Fiber 5

2. Fit of Eq. (1) to Data for the Recovery of Transient Radiation Induced Loss in a Germanium-Phosphosilicate Core Optical Fiber 6

Analytic Models for Radiation Induced Loss in Optical Fibers III. Transient Radiation Effects

1. INTRODUCTION

Two previous RADC technical reports[1,2] presented analytic models for the losses induced in optical fibers as a function of dose under steady-state irradiation conditions. In those reports it was assumed that a state of at least quasi-equilibrium existed between the electron-hole pairs generated during irradiation and the trapping centers in the fiber. Any irradiation during which such equilibrium conditions are not established could be classified as a transient irradiation. However, in this report we define a transient irradiation as exposure to a pulse of radiation of short duration and high dose-rate. The loss induced in the fiber by the radiation pulse generally decreases (recovers) during the time following

(Received for publication 21 February 1985)

1. Wall, J.A. (1984) Analytic Models for Radiation Induced Loss in Optical Fibers I, RADC-TR-84-71, Rome Air Development Center, Griffiss AFB, N.Y.

2. Wall, J.A. (1984) Analytic Models for Radiation Induced Loss in Optical Fibers II. A Physical Model, RADC-TR-84-155, Rome Air Development Center, Griffiss AFB, N.Y.

the pulse. A model for the recovery of transient induced loss in optical fibers, developed to describe the results of irradiations performed at RADC*, will be presented.

The recovery of transient radiation induced loss in optical fibers is a result of the time-dependent recombination of electron-hole pairs generated in the fibers by the radiation. Such recombination processes are important in many phenomena addressed by electronic solid-state physics, such as the decay of luminescence and the time dependence of photoconductivity. There have therefore been a number of theoretical models developed to explain the variety of possible recombination processes. Attempts have been made to apply these models to the recovery of transient induced loss in optical fibers (see, for example, Mattern et al[5] and Looney et al[6]) with limited success. It is not clear, however, whether or not such models are suitable for the description of the recovery of induced loss in optical fibers and it is possible that the phenomena assumed in developing a particular model may not be those that occur in a fiber even though the model may give a good fit to experimental data. Because of these uncertainties, an analytic model for the recovery of transient radiation induced loss in optical fibers was sought that would fit the data well but not necessarily be related to a physical model.

2. MODEL SELECTION

One of the first analytic models tested to describe the recovery of transient induced loss in optical fibers was a sum of exponential terms. This could be related to a possible physical model in which each term represented a type of

---

*In the transient radiation tests performed at RADC, 20 nsec x-ray pulses with nominal peak energy of 2 MeV and dose rates to greater than 10^9 rad/sec were used. Details of the irradiations are described elsewhere.[3,4]

3. Wall, J.A., Posen, H., and Jaeger, R. (1981) Temperature response of germanium phosphosilicate optical fibers under irradiation, in Physics of Fiber Optics, Advances in Ceramics, B. Bendow and S.S. Mitra, Eds., American Ceramic Society 2:398.

4. Wall, J.A. (1983) The Effect of Temperature on the Radiation Induced Losses of Large Diameter GPS and GBS Core Optical Fibers, RADC-TR-83-288, Rome Air Development Center, Griffiss AFB, N.Y.

5. Mattern, P.L., Watkins, L.M., Skoog, C.D., and Barsis, E.H. (1975) Absorption induced in optical waveguides by pulsed electrons as a function of temperature, low dose rate gamma and beta rays, and 14 MeV neutrons, IEEE Trans. Nuc. Sci. NS-22:2468.

6. Looney, L.D., Turquet de Beauregard, G., Lyons, P.B., and Kelly, R.E. (1981) Radiation induced transient absorption in optical fibers, Proc. SPIE 296:17.

trapping center with a unique temporal probability for the release and subsequent recombination of an electron or hole. It was found that most of the RADC data on transient induced loss in optical fibers could be fit to this model using three exponential terms. However, another model was sought, because the exponential model was difficult to fit to the data since it required the determination of six constants (two for each term). Also, its usefulness in providing a physical interpretation of the data was questionable because any continuous mathematical function can be represented by the sum of a sufficient number of exponential terms.

Since a number of the theoretical models for electron-hole recombination processes could be approximated by a function of the form ct^{-n}, where t is the time and c and n are constants, a model of this form was tested. It was found to fit the data fairly well over much of the time span covered by the data, but has the obvious disadvantage of tending to infinity at short times. To avoid this disadvantage the function was arbitrarily modified to the form:

$$L = \frac{a}{1 + bt^n} \quad , \tag{1}$$

where

L = radiation induced loss

t = time after radiation pulse, and

a, b, and n are constants.

This expression was found to fit the transient data quite well. Although not related to a physical model, Eq. (1) has the form theoretically derived for the bimolecular recombination process if n = 1. Also, according to Haug,[7] it could be an approximation for thermally activated recombination and according to Brown,[8] it could represent recombination from an exponential distribution of traps.

To give a complete description of transient radiation induced loss data a constant or term that decreases slowly with time should be added to Eq. (1) to account for permanent or long-term induced loss. However, because the total dose received by the optical fibers during the transient radiation tests at RADC was so small (less than 50 rad), this factor will be neglected.

7. Haug, A. (1972) Theoretical Solid State Physics Volume 2, Pergamon Press, pp. 292-295.

8. Brown, F.C. (1966) The Physics of Solids, W.A. Benjamin Inc., N.Y., p. 391.

3. DATA FITTING PROCEDURE

To determine the constants in Eq. (1) for a specific set of transient induced loss data, it is convenient to express the data in terms of reciprocal loss as a function of time. Instead of Eq. (1), we then fit

$$L^{-1} = \frac{1}{a} + \frac{b}{a} t^n \tag{2}$$

and determine the reciprocal of a, b/a, and n. This expression can be readily fit using the "Gauss-Newton" method mentioned in Ref. 2. However, good fits have been obtained using the following procedure, which is also useful for obtaining estimates of the constants needed for the Gauss-Newton method.

The first derivative of Eq. (2) is

$$\frac{d}{dt}(L^{-1}) = \frac{b}{a} n t^{n-1} \quad . \tag{3}$$

Using a finite difference method to approximate the differential from the data and a standard procedure for fitting a power function (see Ref. 1 for example) a value for n (actually n-1) is obtained. When the time data are converted to the n^{th} power of time, a linear fit to the reciprocal of the induced loss [Eq. (2)] gives the required values of 1/a and b/a.

It should be noted that when the data are fitted to the approximation of Eq. (3), low values of the correlation coefficient for the fitting procedure may frequently be obtained. This is probably due to the approximation of the differential and seems to have little relation to the final result, since high values of the correlation coefficient have usually been obtained for the fit to Eq. (2).

4. RESULTS

Figure 1 shows the results of a fit of Eq. (1) to data for the recovery of transient radiation induced loss in a germanium-borosilicate core optical fiber. The fit is very good and the deviation of the calculated curve from the data points is generally well within the estimated ± 3 dB/km precision of the data. Figure 2 shows two fits of Eq. (1) to transient data for a germanium-phosphosilicate core optical fiber. The first fit (solid curve) utilized all of the data up to 100 μsec. As can be seen in the figure the fit is not very good below 2 μsec. For the second fit (dashed curve), points taken near the ends of the oscilloscope traces (the data were read from four separate oscilloscope beams), which are difficult to read with reasonable accuracy, were eliminated. The second fit is clearly much better

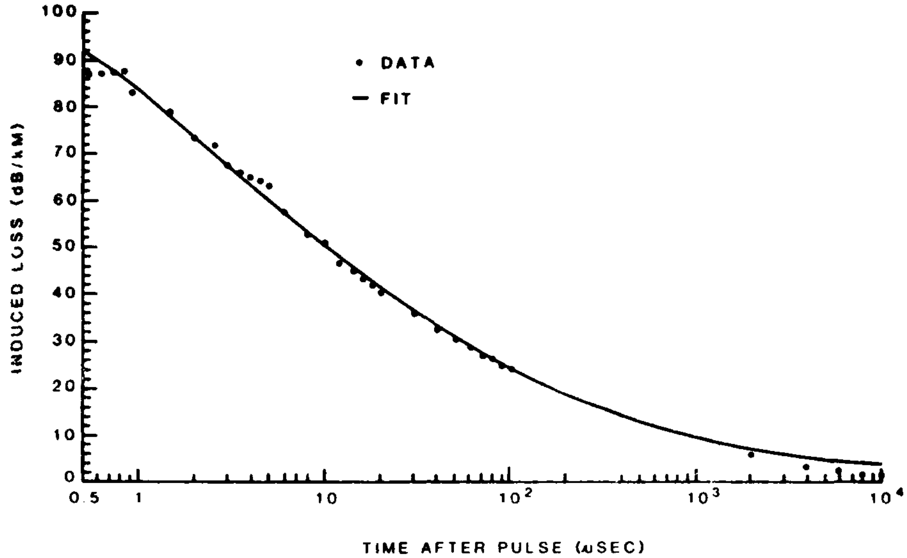


Figure 1. Fit of Eq. (1) to Data for the Recovery of Transient Radiation Induced Loss in a Germanium-borosilicate Core Optical Fiber. The irradiation conditions were: pulse width, 20 nsec; dose-rate, 1.3×10^9 rad/sec; peak x-ray energy, 2 MeV; temperature 25C; source wavelength 820 nm

than the first. In both figures, the fitted curves deviate somewhat more from the data for times longer than 100 μsec. This could be due to small differences in the calibrations of the oscilloscope amplifiers and/or time bases, which may influence the accuracy of the data in this time range where the signal to noise ratio is low. This possibility is most evident in Figure 2 where the data shows a greater loss remaining at 400 μsec than at 100 μsec, a very unlikely event.

Transient data for more than 12 optical fibers were fit to Eq. (1) with results similar to those shown in Figures 1 and 2. Good fits were also obtained on fibers irradiated at temperatures of -55 and +125C. Considering the time spans involved as well as the inherent "noise" associated with the acquisition of transient data, this is remarkable for an expression requiring the determination of only three constants.

5. DISCUSSION

The success of Eq. (1) in describing the recovery of transient radiation induced loss in optical fibers cannot be explained except that it may be a good approximation to several physical models developed to explain electron-hole

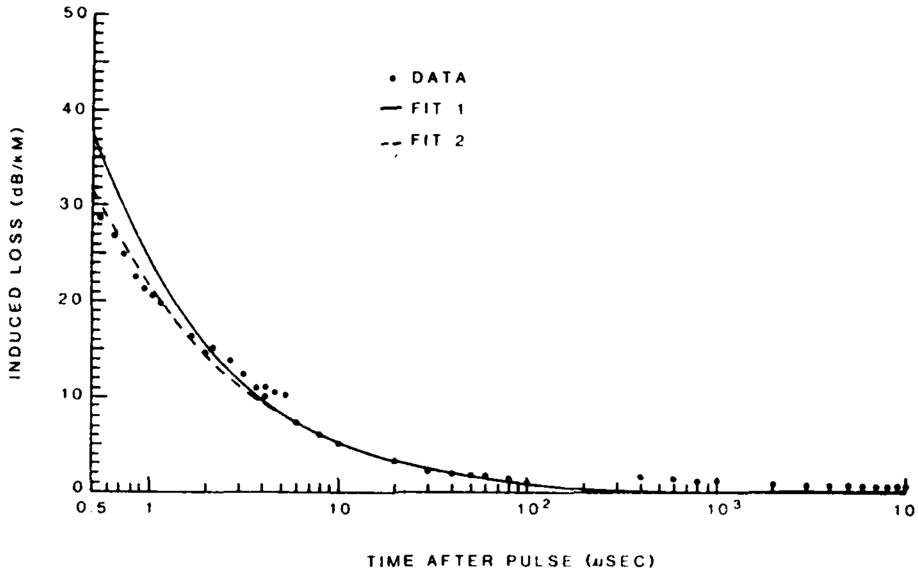


Figure 2. Fit of Eq. (1) to Data for the Recovery of Transient Radiation Induced Loss in a Germanium-Phosphosilicate Core Optical Fiber. Fit 1 (solid curve), all data used. Fit 2 (dashed curve), data of questionable accuracy eliminated (see text). The irradiation conditions were: pulse width, 20 nsec; dose rate, 1.1×10^9 rad/sec; peak x-ray energy, 2 MeV; temperature, 25C; source wavelength, 820 nm

recombination processes in other materials. Evidence that Eq. (1) has some degree of "universality" is given by the fact that, with the addition of a constant to account for permanent induced loss, it could be used to fit data on the recovery of induced loss in optical fibers following steady-state irradiation. [Specifically, Eq. (1) plus a constant gave very good fits to the data shown in Figures 3 and 4 of Ref. 4.] However, there is insufficient information available at this time to determine whether or not the constants obtained in fitting Eq. (1) to data may be dose-rate and/or dose dependent. Any extrapolation of the results of data fits to Eq. (1) should therefore be performed with this uncertainty in mind. Also, because of the complexity of the dynamics of electron-hole trapping and release processes, it is possible that Eq. (1) may not be applicable to data obtained for irradiations performed at much higher doses and dose-rates or taken at shorter times than those for which the data fits described in the report were performed.

References

1. Wall, J.A. (1984) Analytic Models for Radiation Induced Loss in Optical Fibers I, RADC-TR-84-71, Rome Air Development Center, Griffiss AFB, N.Y.

2. Wall, J.A. (1984) Analytic Models for Radiation Induced Loss in Optical Fibers II. A Physical Model, RADC-TR-84-155, Rome Air Development Center, Griffiss AFB, N.Y.

3. Wall, J.A., Posen, H., and Jaeger, R. (1981) Temperature response of germanium phosphosilicate optical fibers under irradiation, in Physics of Fiber Optics, Advances in Ceramics, B. Bendow and S.S. Mitra, Eds., American Ceramic Society 2:398.

4. Wall, J.A. (1983) The Effect of Temperature on the Radiation Induced Losses of Large Diameter GPS and GBS Core Optical Fibers, RADC-TR-83-288, Rome Air Development Center, Griffiss AFB, N.Y.

5. Mattern, P.L., Watkins, L.M., Skoog, C.D., and Barsis, E.H. (1975) Absorption induced in optical waveguides by pulsed electrons as a function of temperature, low dose rate gamma and beta rays, and 14 MeV neutrons, IEEE Trans. Nuc. Sci. NS-22:2468.

6. Looney, L.D., Turquet de Beauregard, G., Lyons, P.B., and Kelly, R.E. (1981) Radiation induced transient absorption in optical fibers, Proc. SPIE 296:17.

7. Haug, A. (1972) Theoretical Solid State Physics Volume 2, Pergamon Press, pp. 292-295.

8. Brown, F.C. (1966) The Physics of Solids, W.A. Benjamin Inc., N.Y., p. 391.

MISSION
of
Rome Air Development Center

RADC plans and executes research, development, test and selected acquisition programs in support of Command, Control, Communications and Intelligence (C^3I) activities. Technical and engineering support within areas of competence is provided to ESD Program Offices (POs) and other ESD elements to perform effective acquisition of C^3I systems. The areas of technical competence include communications, command and control, battle management, information processing, surveillance sensors, intelligence data collection and handling, solid state sciences, electromagnetics, and propagation, and electronic, maintainability, and compatibility.

Printed by
United States Air Force
Hanscom AFB, Mass. 01731

SECURITY CLASSIFICATION OF THIS PAGE

SECURITY CLASSIFICATION OF THIS PAGE

END

FILMED

9-85

DTIC